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INSEGT FIBRE: A POWERFUL SEGMENTATION TOOL FOR QUANTIFYING FIBRE ARCHITECTURE IN COMPOSITES

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Summary: *Insegt Fibre* is a tool for volumetric fibre segmentation, that is appropriate for densely packed fibres. The robustness to image quality of the underlying dictionary-based algorithm has opened up new opportunities for micro-structural characterisation of fibre-reinforced polymers. The recent user-friendly version of the robust fibre-detection algorithm makes image-based characterisation of fibrous materials simpler and more accessible.

1. INTRODUCTION

Fibre-reinforced composites (FRC) are employed in a wide range of applications for their high strength and stiffness relative to their weight. The mechanical properties of FRC are highly related to their internal structure all the way down to the micro-scale, where individual fibres can be resolved. A recent technique for characterising the diameters, orientation and arrangement of fibres is X-ray micro-computed tomography (micro-CT).

To measure individual fibres from micro-CT scans, the chosen image segmentation method should not only separate the fibre phase from the matrix material, but also the fibres from one another. The lower the quality of the scan, the harder it is to separate fibres from one another when these are densely packed inside the material.

Scans of limited spatial resolution and contrast between material phases (especially poor for carbon fibres embedded in epoxy) require segmentation methods that are highly robust to noise and artefacts. The spatial resolution of a scan can be limited in sequences of ultra-fast scans, necessary to capture the very sudden micro-structural changes in composites under load. Selecting coarser pixel sizes, to include as many fibres as possible in the scan, will also reduce the spatial resolution. Overall, lower requirements on the image quality will broaden the application of image-based composite characterisation and make it available to a broader range of scientists.

We hereby present a software tool for robust detection of individual fibres in 3D, and discuss its potential for micro-structural characterisation of FRC. The user-friendly tool is called *Insegt Fibre* and it is based on the segmentation algorithm by Emerson et al. [1], which has proven to be precise for a variety of scan qualities and fibre materials [1, 2]. As the aim of *Insegt Fibre* is to make image-based fibre characterisation simpler and more accessible, the software is available online for free¹, together with a user manual, example scripts and data.

2. METHOD

Insegt Fibre builds upon the dictionary-based fibre detection algorithm presented in [1]. Besides providing a user-friendly interface, the underlying algorithm has undergone three main improvements since [1]: i) minimisation of the user-input required to learn the dictionary model, ii) a faster dictionary-learning stage, and iii) a more robust tracking stage.

Improvements i and ii are packed behind a graphical user interface (GUI), through which the dictionary is learnt interactively from user-input [3]. Every time the user marks a new pixel on the training image (left display in GUI, see Fig. 1(a)), the dictionary model will be updated. A dictionary update will also trigger

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¹Science cases at www.qim.compute.dtu.dk, soon to be hosted at www.qim.dk

a new segmentation of the training image, which will be immediately shown on the right display of the GUI (see Fig. 1(a)). Once the user is satisfied with the segmentation of the training image, the dictionary can be exported, as it is ready to process the batch of slices comprising the composite scan.

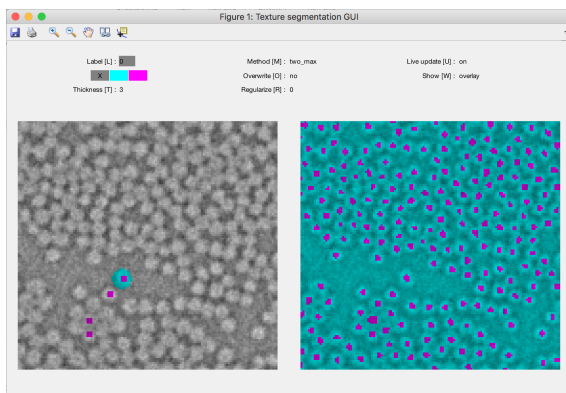
Improvement number iii increases the robustness of the tracking to inaccuracies in detecting the fibres and thus to image quality. To form three-dimensional fibre trajectories, centre detections from contiguous slices are now matched in a bidirectional manner. Additionally, for those rare occasions in which a single fibre is assigned more than just one centre detection per slice, a system to handle multiple detections has been added.

3. RESULTS AND DISCUSSION

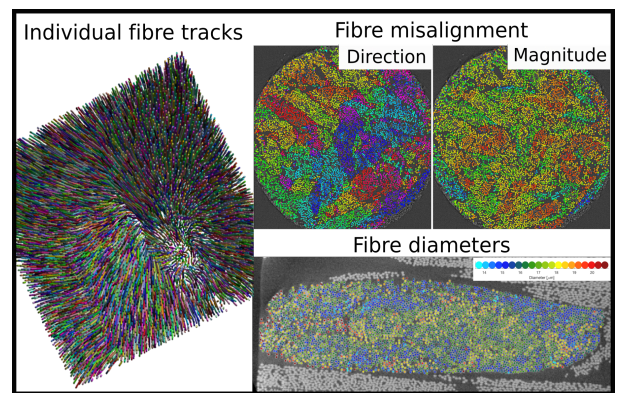
As the method is able to reveal fibre orientations and diameter distributions in complete bundles (see Fig.1(b)), it is useful for assessing the effect of manufacturing on the diameters and alignment of fibres, and ultimately on the material's mechanical properties. In [1], the compression strengths of a glass and carbon fibre composite were estimated from the orientations of the segmented fibre trajectories. The measured diameters and trajectories can also be used to create a finite element model (FEM). In [5], the transverse stiffness was estimated from the image-based FEM generated with the segmented fibre characteristics. What is more, the method is useful for tracking fibre deformations during time-lapse imaging of composite testing. Following the very small changes in each individual fibre under progressive loading conditions, and correlating these with the initial structure of the material, can reveal the precursors to the very complex damage mechanisms that affect fibre composites. This functionality was demonstrated in [4], when investigating fibre reorientation under compression loading.

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(a)



(b)

Figure 1: (a) Graphical user interface for training the dictionary model that will detect fibre cross-sections in the full volume. On the left the manual annotations, and on the right the detected fibre centres. (b) On the left, three-dimensional fibre trajectories measured with the dictionary-based approach. On the right, fibre orientations and diameters computed from the measured fibre trajectories.